NATIONAL BUREAU OF STANDARDS REPORT

5352

A STUDY OF CERTAIN PROCEDURES FOR MEASURING
THE HEAT TRANSFER IN REFRIGERATED TRAILERS

by

C. W. Phillips
J. W. Grimes
P. R. Achenbach

Report to
Transportation and Facilities Branch
Marketing Research Division
Agricultural Marketing Service
U. S. Department of Agriculture
Washington 25, D. C.

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U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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C. W. Phillips
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Air Conditioning, Heating, and Refrigeration Section
Building Technology Division

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Abstract

At the request of the Transportation and Facilities Branch, Marketing Research Division, Agricultural Marketing Service, of the Department of Agriculture, studies were made to determine the time required to attain steady-state heat transfer in a typical refrigerated semi-trailer under two laboratory procedures, and to develop and describe an accurate method for measuring brine temperatures during rating tests of trailers. Representatives of the National Bureau of Standards were requested to present the principles of the metering heat sink method for rating refrigerated structures to the truck and trailer manufacturing industries using models and graphical materials developed for the purpose. The tests of a typical 35-foot semi-trailer with 6-inches of glass fiber insulation in walls, ceiling, and floor showed that steady-state heat transfer was approached only after subjecting it to the desired temperature conditions for a minimum of 24 hours. The lag in attaining steady-state heat transfer was approximately the same whether a fixed quantity of heat was supplied inside the trailer or whether a fixed temperature difference between inside and outside the trailer was established as soon as possible after starting the test. Recommended methods of temperature measurement are described in the report as well as the procedures used for disseminating information on the metering heat sink method for rating refrigerated structures.

INTRODUCTION

In recent years the increased use of frozen food products has created a need for the transportation of these frozen products. This need for transportation has resulted in a tremendous increase in the use of refrigerated semi-trailers. The Transportation and Facilities Branch, Agricultural Marketing Service, U. S. Department of Agriculture, has been interested in and worked on some of the technical problems of frozen food transportation for several years. The Air Conditioning, Heating, and Refrigeration Section of the National Bureau of Standards has made a number of measurements of the heat transfer of refrigerated semi-trailers in connection with their studies of the performance of such vehicles for the Quartermaster Research and Engineering Command, Department of the Army.

Because of the lack of a standard method or standard conditions for rating the heat transfer of refrigerated semi-trailers, and because they recognized that such standards would be desirable, the American Trucking Associations, Inc., in October, 1955, requested the National Bureau of Standards to submit a project proposal for developing standard rating conditions and a simple rating method and apparatus to determine the heat transfer characteristics of such vehicles. Although this program was not initiated, the National Bureau of Standards and the U. S. Department of Agriculture conducted a comparative study of seven typical refrigerated semi-trailers in Edgewater Park, Mississippi, in May, 1956. The trailers were submitted by members of the Truck-Trailer Manufacturers Association at the request of the American Trucking Associations, Inc. The results of this test were reported in NBS Report No. 4875, entitled "A Comparison of the Heat Transfer Characteristics of Seven Typical Refrigerated Semi-Trailers" in October, 1956. The wide variations in the various heat transfer characteristics of these seven vehicles and in the performance of their refrigerating units further emphasized the need for standard rating techniques. Concurrently with this activity, the National Bureau of Standards was developing in cooperation with the Quartermaster Research and Engineering Command Department of the Army, a prototype metering heat sink apparatus for measuring the heat transfer of a refrigerated structure (such as a trailer) while the structure was refrigerated under conditions normal to intended service.

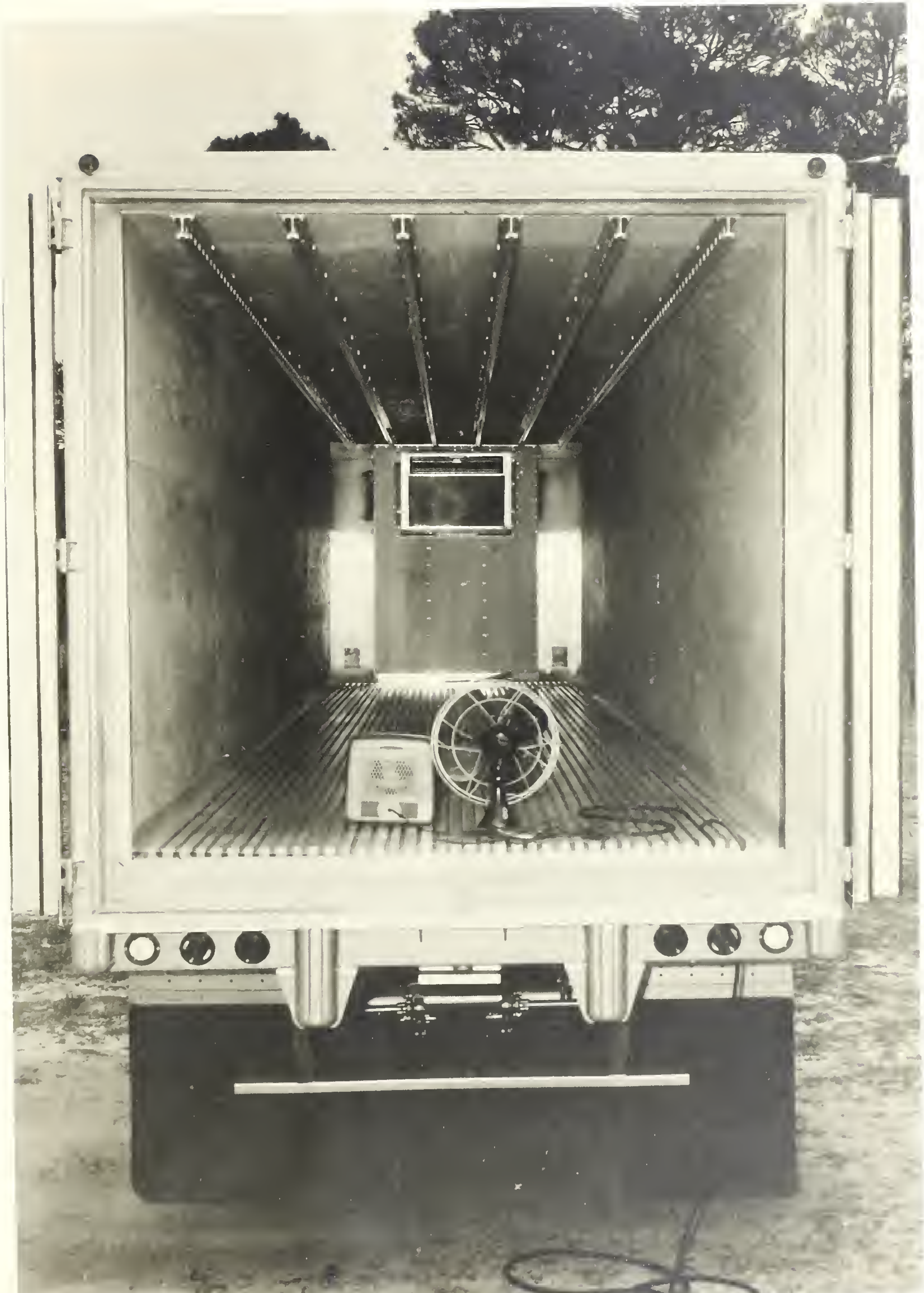


Figure 1

The Transportation and Facilities Branch of the U. S. Department of Agriculture, in December, 1956, requested the National Bureau of Standards to make certain studies designed to further the development and acceptance of standard rating conditions and test methods. The requested work was described as a part of a continuing study of various methods of measuring heat transfer of refrigerated vehicles lending to selection of the most accurate and practicable method, which may be adopted as a standard for the measurement of trailer performance by the trucking and truck manufacturing industries, since previous cooperative studies by the National Bureau of Standards and the U. S. Department of Agriculture had indicated that a method which refrigerates the interior of the vehicle under test is desirable.

The request incorporated the following four tasks:

1. Make laboratory tests of a typical 35-foot refrigerated semi-trailer to determine the length of time required for steady-state heat transfer under controlled heat loss conditions.

2. Determine the best means for the measurement of temperature difference in secondary refrigerant lines. Select best means of instrumentation.

3. Prepare charts and other apparatus which may be used to demonstrate and explain the basic recommended method to the truck-trailer manufacturing industry and other interested groups.

4. After this has been done, the results of the research program up to that point will be presented to the truck-trailer manufacturing industry, at which time determination will be made jointly by the National Bureau of Standards, the U. S. Department of Agriculture, and the Truck-Trailer Manufacturers Association as to further work to be done, to be supported primarily by funds contributed by that industry.

This report describes the work done to complete these four tasks.

Task 1

"Make laboratory tests of a typical 35-foot refrigerated semi-trailer to determine the length of time required for steady-state heat transfer under controlled heat loss conditions."

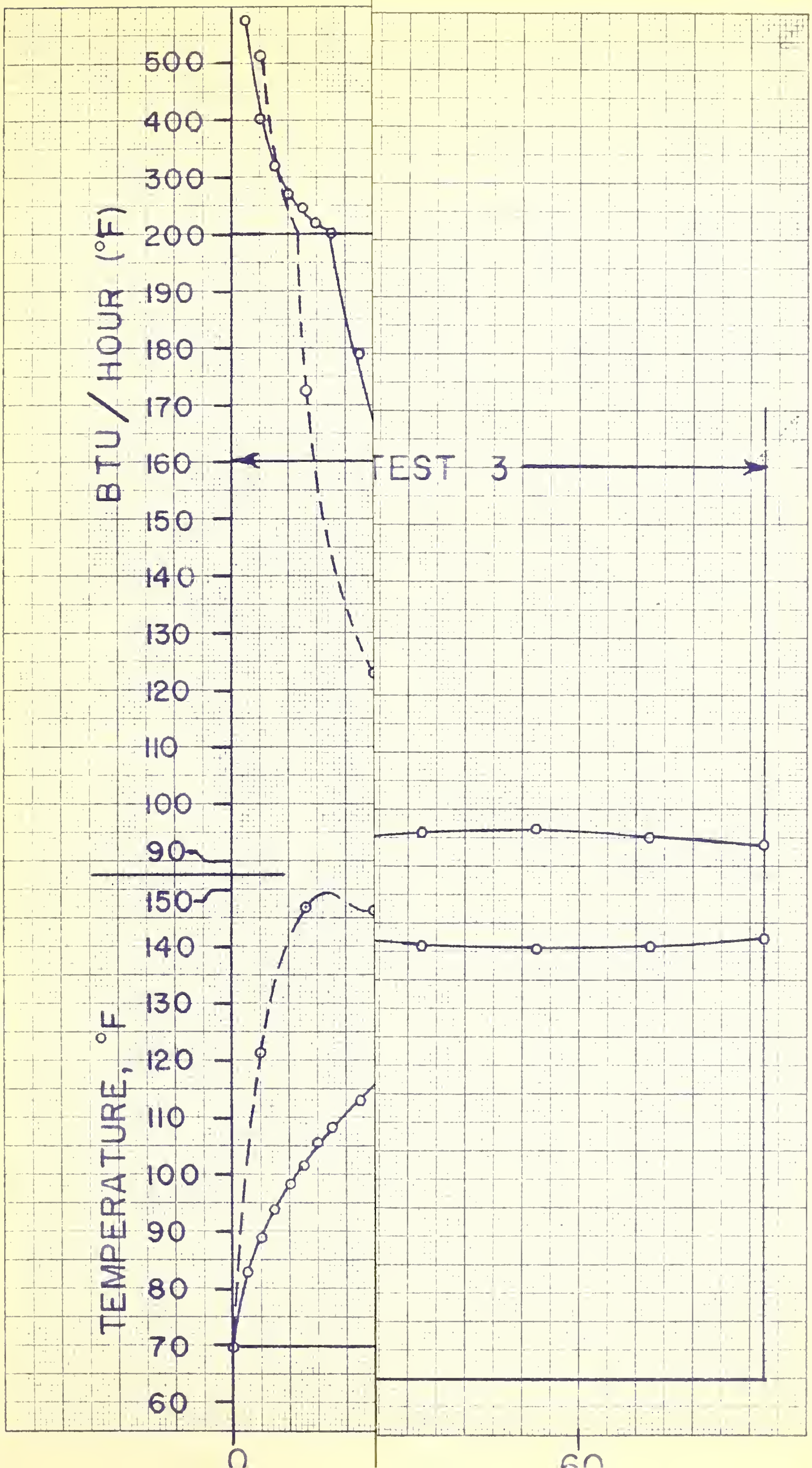
A secondary purpose of this test was to evaluate the adequacy of short heat loss tests, some reported as short as ten to twelve hours, to determine the heat transfer rate of a refrigerated trailer.

A 35-foot Trailmobile refrigerated semi-trailer, Model No. T/M C-8222, Serial No. 1-17126, manufactured by Trailmobile, Inc., was used for the three tests made. This was the same trailer furnished by Trailmobile, Inc., for the May, 1956, tests at Edgewater Park, Mississippi. Figure 1 is a photograph of the interior of the specimen looking through the trailer doors. The fan and heater shown in the figure were not used for these tests.

The trailer was equipped with a Thermo King refrigerating unit, Model RL-30, which remained in place during the tests but was not operated. The trailer had six meat rails, had an aluminum exterior skin and a plywood interior skin, and was insulated with six inches of Ultralite in the walls, floor, and ceiling. It was equipped with a tandem wheel assembly (two axles, four double wheels) and weighed 13,092 lbs, according to the manufacturer's delivery acknowledgement.

For the tests, the trailer was placed in an enclosure in which the temperature could be controlled. An electric heater and two 16-in. desk fans were placed in the trailer and means were provided to record the amount of power supplied to them. Thermocouples were installed on the interior and exterior of the trailer to measure the respective temperatures of the air inside and out. All exterior thermocouples, four in number, were mounted six inches from the exterior surfaces, and one set of twelve interior thermocouples was mounted six inches from the interior surfaces. Another set of three thermocouples was installed in the trailer interior, one in the exact center of the vehicle, the other two at midheight on the longitudinal center line, 1/6 of the interior length from either end. These two sets were installed for comparative purposes, to determine whether the set of three would be adequate for a proposed standard test procedure.

For the first test, the trailer was left open and allowed to come to thermal equilibrium in an ambient temperature of 70°F during a period of more than 24 hours. The doors were then closed, the interior fans started, and sufficient electrical heating supplied to bring the interior temperature of the trailer to about 150°F in approximately



BTU / HOUR (°F)
500
400
300
200
190
180
170
160
150
140
130
120
110
100
90
TEST 3
TEMPERATURE, °F
150
140
130
120
110
100
90
80
70
60
0
60

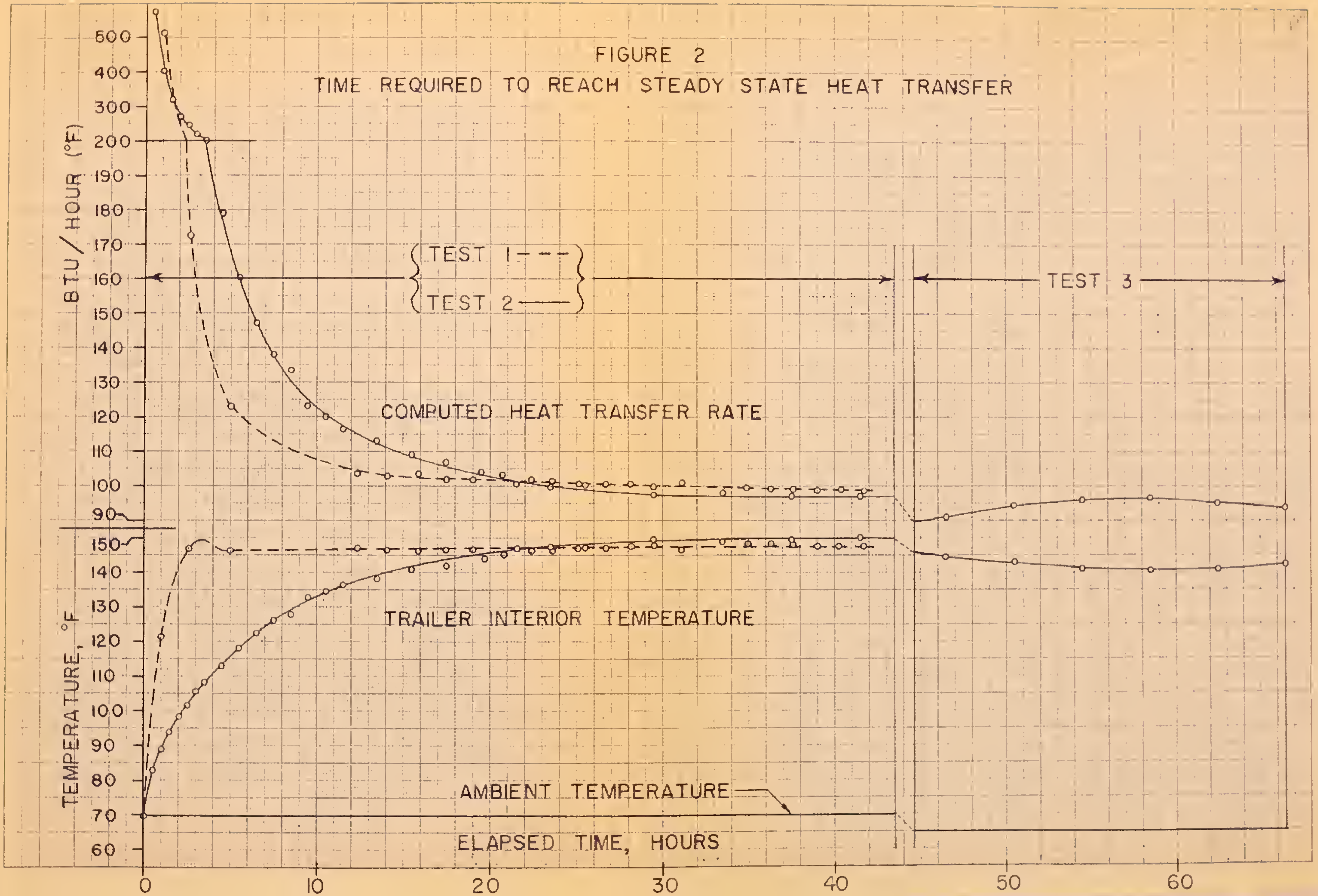


FIGURE 2
TIME REQUIRED TO REACH STEADY STATE HEAT TRANSFER
BTU / HOUR (°F)
TEST 1
TEST 2
TEST 3
COMPUTED HEAT TRANSFER RATE
TRAILER INTERIOR TEMPERATURE
TEMPERATURE, °F
AMBIENT TEMPERATURE
ELAPSED TIME, HOURS

2 1/2 hours. A thermostat in the trailer then regulated the heating to hold the interior temperature at 150°F. The power required was observed at regular intervals for more than 45 hours.

For the second test, the trailer was again permitted to come to thermal equilibrium at 70°F. The doors were then closed, the interior fans started, and the amount of electric heating required in the first test to hold the interior at 150°F was supplied. The interior temperature of the trailer, therefore, rose much more slowly than in the first test. This test was also continued for more than 45 hours.

The third test consisted of reducing the ambient temperature from 70°F to 60°F at the conclusion of the second test, with all other conditions unchanged, to determine the length of time required for the heat transfer rate to again become constant.

During the three tests, the trailer decreased approximately 40 lbs. in weight. Water began to drip from approximately 26 points around the bottom edge of the exterior skin soon after the interior temperature reached 150°F, and continuing for about four hours in Test 1. Again in Test 3, when the ambient temperature was lowered from 70°F to 60°F, water dripped for about three hours from most of the same places. No volumetric measurement was made of the amount of water which dripped from the trailer, but it is believed that the weight reduction can be attributed to the water driven from the vehicle during the tests.

The rates at which the apparent heat transfer and interior temperature approached constant values in tests 1, 2, and 3 are shown in Figure 2. It is significant to note in comparing test 1 with test 2 that about the same length of time was required for the heat transfer to come to a steady-state regardless of the initial rate of increase of the interior temperature, and that at least 24 hours of "conditioning" time was required before a steady-state heat loss test could be started. The average of the temperatures indicated by the set of three thermocouples along the center line of the trailer was less than one degree different from the average of the set of twelve thermocouples located six inches from the interior skin, indicating that the air circulation rate was adequate to provide essentially a uniform interior temperature.

In test 3, which was in reality a continuation of test 2, except that the ambient temperature around the trailer was reduced from 70°F to 60°F, it was observed that more than ten hours elapsed before the heat transfer rate again approached a steady-state condition.

DISCUSSION AND CONCLUSIONS - Task 1

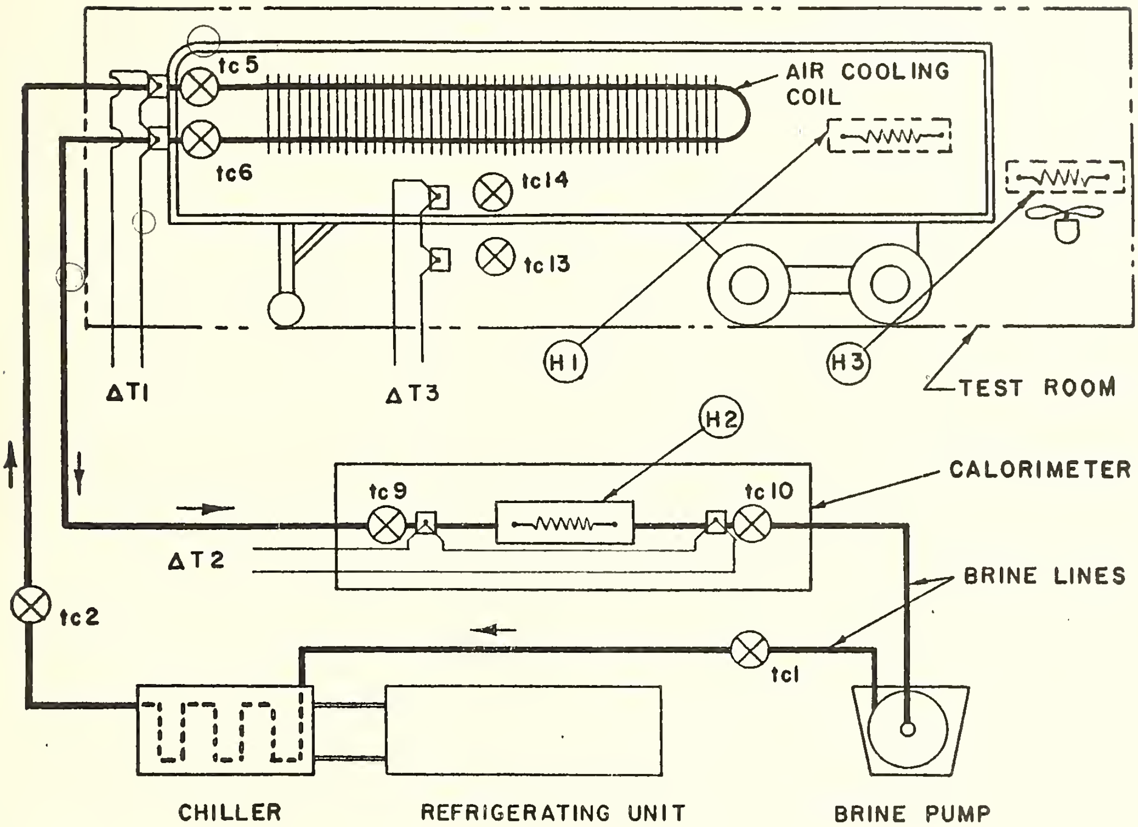
Two significant conclusions are drawn from the data of tests 1 and 2, shown in Figure 2; first, that a "conditioning" period of at least 24 hours is required before a steady-state heat loss test can be initiated of a refrigerated semi-trailer of the type, weight, and degree of insulation typified by the Trailmobile vehicle used for the test, and second; the time required for the vehicle to come to a steady-state heat loss rate is not essentially different whether the interior trailer temperature is changed rapidly at first, as in test 1, or more slowly, as in test 2.

Although these tests were made with the interior temperature higher than the ambient temperature around the trailer, and corollary studies show that determination of heat loss of a refrigerated vehicle by refrigerating the interior is preferable; the information gained by tests 1 and 2 is important because it shows that sufficient refrigerating capacity to reduce the interior temperature rapidly is not necessary. Taking advantage of this finding will reduce the size and cost of the refrigerating apparatus required for such a test.

Tests 1 and 2 also point out the desirability of observing and recording temperature and heating or cooling loads during the "conditioning" period in such a manner as to indicate when the apparent heat transfer rate does not change more than, say, one percent for two consecutive six-hour periods. If the data is so recorded it can be used to indicate when the steady-state heat transfer test can be started. For example, applying this rule to test 1, it would indicate that a six-hour steady-state test could have been started at about the 28th hour and for test 2 at about the 34th hour.

Although tests 1 and 2 were not intended as "rating" tests it was interesting to note that under the existing conditions the heat loss of the trailer was 98.3 Btu per

HEAT TRANSFER CALORIMETER FOR REFRIGERATED SEMI-TRAILERS*



SYMBOLS:

$\Delta T1$	TEMPERATURE DIFFERENCE OF BRINE ACROSS TRAILER
$\Delta T2$	" " " " " CALORIMETER
$\Delta T3$	" " BETWEEN AIR IN TRAILER AND TEST ROOM
tc1, tc2, tc3, etc.	TEMPERATURE MEASUREMENT POINTS
(H1), (H2), etc.	ELECTRIC HEATERS RATED IN BTU/HOUR

EQUATION FOR HEAT GAIN OF TRAILERS:

$$\text{BTU PER HOUR (°F)} = \frac{\frac{\Delta T1}{\Delta T2}(H2) - (H1)}{\Delta T3}$$

* "DEVELOPED BY NAT'L BUREAU OF STANDARDS"

FIGURE 3

LOCATION OF THERMOCOUPLE WELLS IN SECONDARY REFRIGERANT CIRCUIT

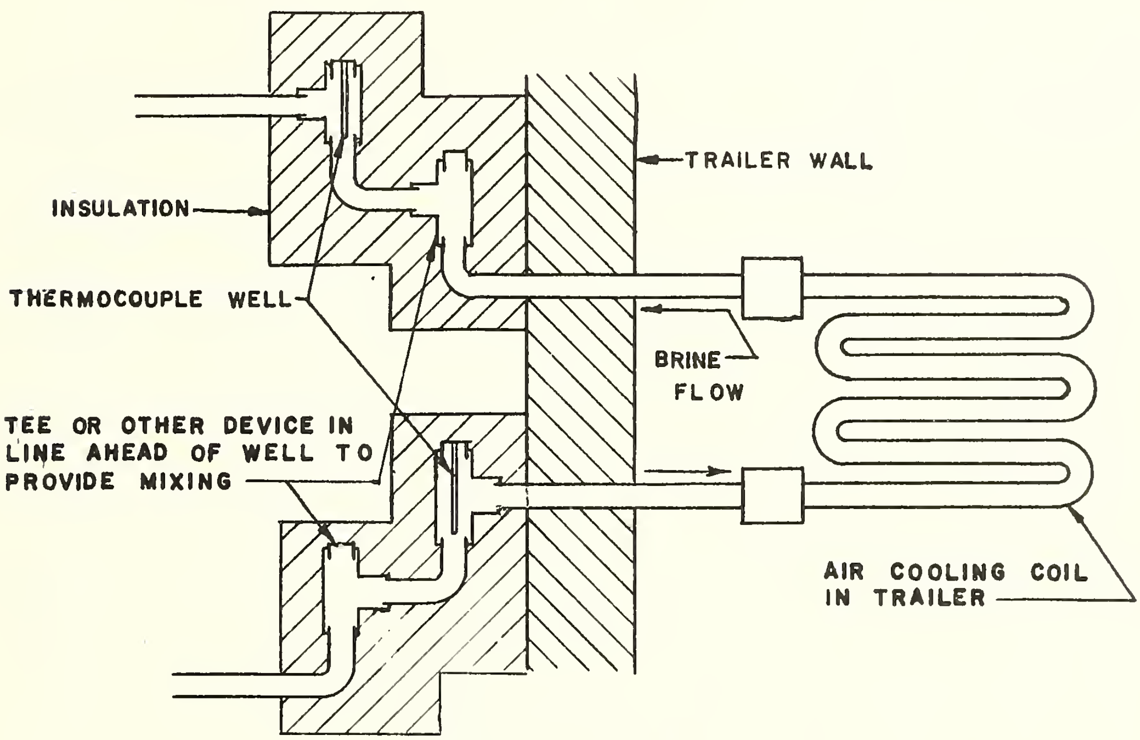


FIGURE 4A

THERMOCOUPLE CIRCUIT FOR MEASUREMENT OF TEMPERATURE DIFFERENCE

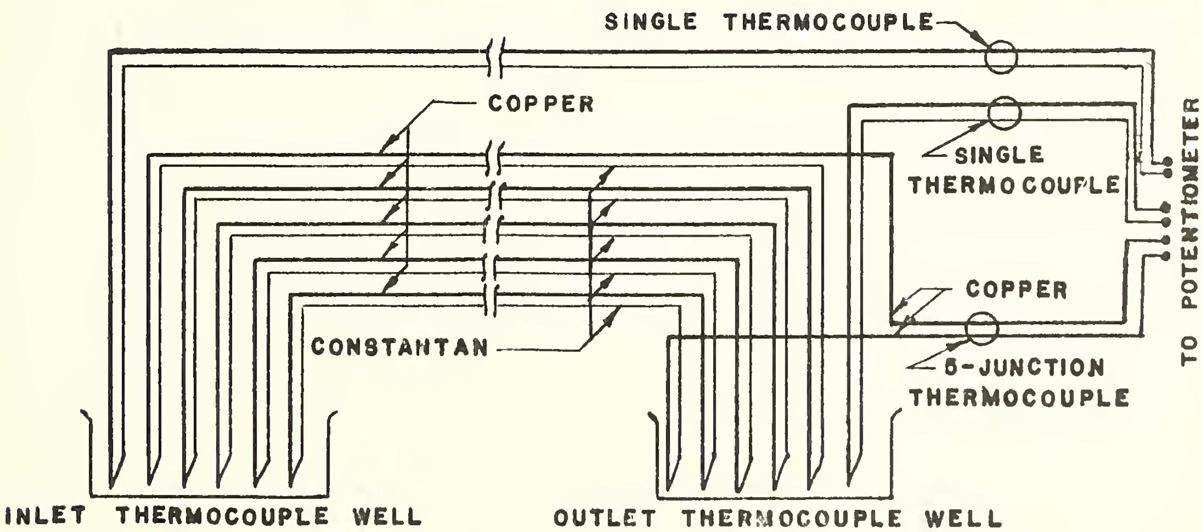


FIGURE 4B

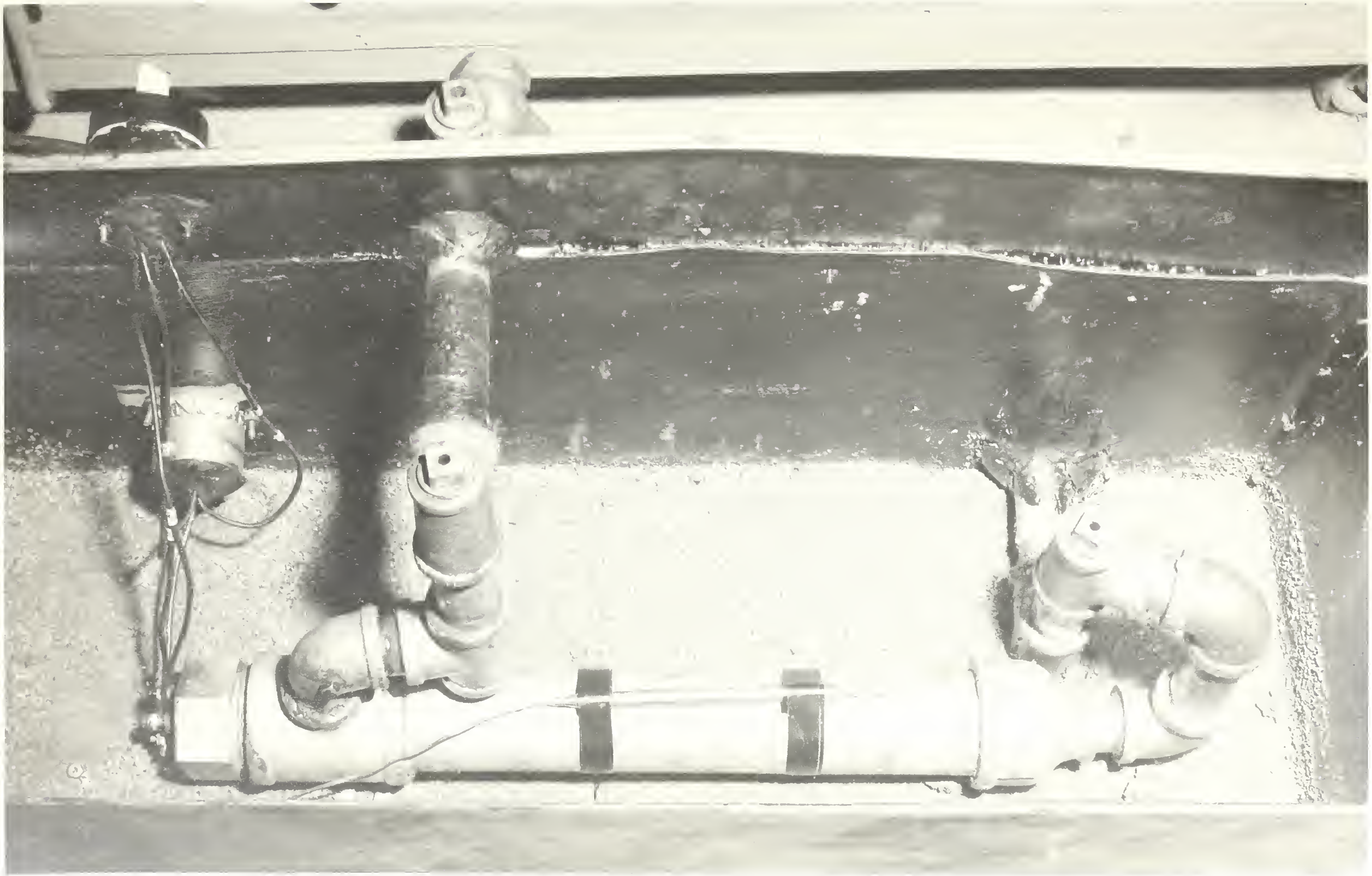


Figure 5

TYPICAL THERMOCOUPLE WELL IN 3/4" FITTING

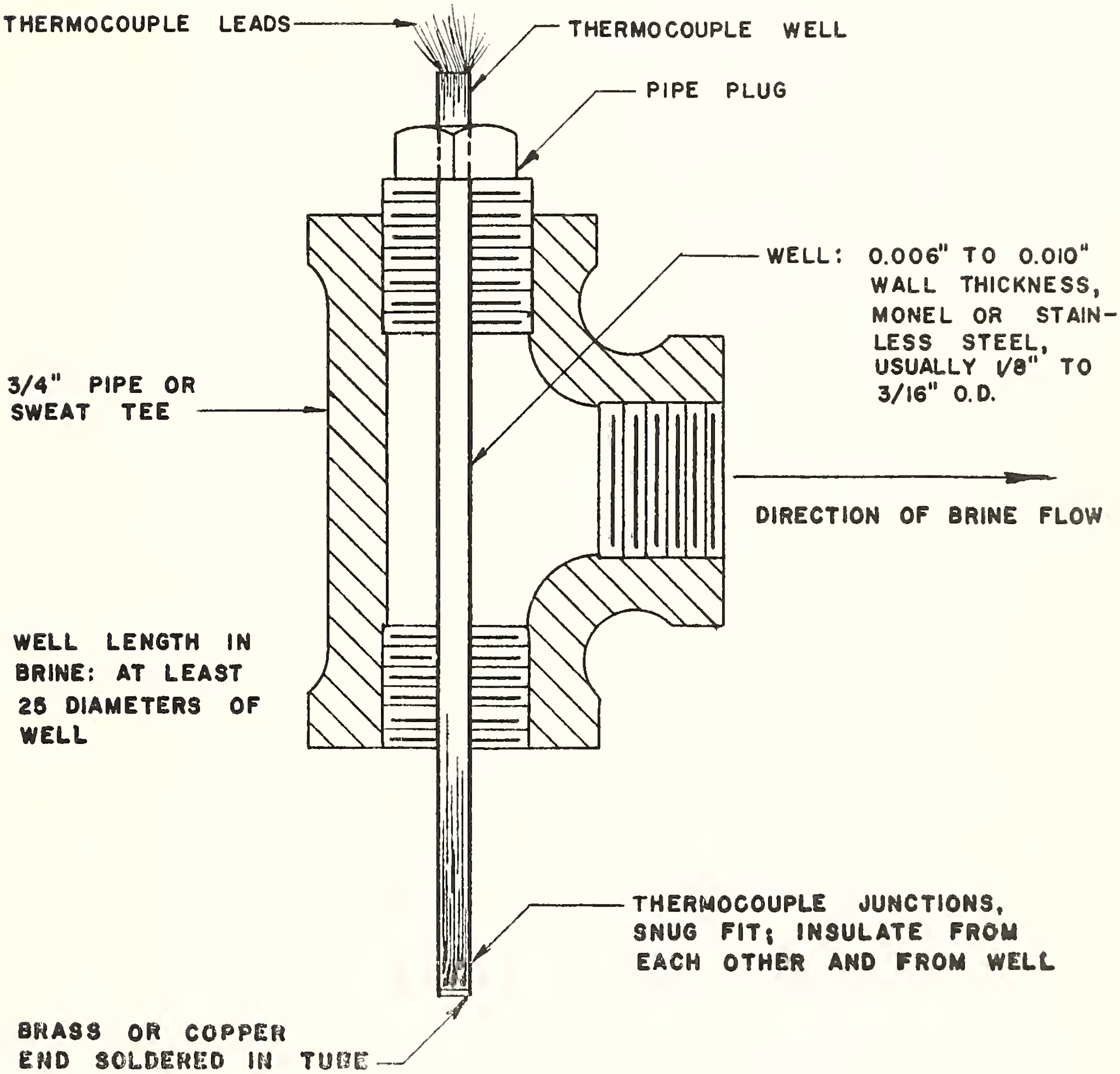


FIGURE 6

hour (°F) at the end of test 1 and 96.9 Btu per hour (°F) at the end of test 2.

Task 2

"Determine the best means for the measurement of temperature difference in secondary refrigerant lines. Select best means of instrumentation."

Concurrent studies of methods for determining the heat transfer rate of refrigerated structures for the Quartermaster Research and Engineering Command, Department of the Army, has indicated that a "metering heat sink" such as shown diagrammatically in Figure 3 has several advantages over the heat loss method. The most important advantage of the metering heat sink method, which refrigerates the interior of the structure under test to the temperature at which it is designed to operate, measures the heat transfer of the walls, roof, and ceiling at the same mean temperature, and with the same direction of heat flow as in normal service. Further, it provides for normal movement of water vapor into or through the walls of the structure under test, since the ambient conditions of temperature and humidity are also maintained at normal service levels.

Figure 4 (A) shows the design of the thermocouple wells and piping adjacent to them which have been found satisfactory for the accurate determination of the temperature difference of the secondary refrigerant or brine entering and leaving the trailer under test, and entering and leaving the calorimeter or calibrated heater (see H2 in Figure 3). Five copper-constantan thermocouples are series-connected with the "cold" junctionsin one of the two wells and the "hot" junctions in the other. Since the emf per degree produced by a single pair of copper-constantan junctions is about 20 microvolts, the five thermocouples in series produce a measuring signal of about 100 microvolts per degree of temperature difference of the two wells. Figure 4 (B) shows the wiring circuit for such a differential thermocouple. Figure 5 is a view of a calibrated heater, showing the piping arrangement and thermocouple wells. Figure 6 shows the construction of a typical thermocouple well. Conventional commercial electronic indicating or recording potentiometers have been found satisfactory.

With a brine temperature difference of eight degrees, the five thermocouples in series produce a signal of about 800 microvolts and since these potentiometers depending on type and range, can indicate or record with an accuracy of from three to ten microvolts, the temperature difference can readily be measured within two percent. It should be noted that corrections must be made for the change in emf per degree produced by the differential thermocouples with change in the absolute temperature of the thermocouple.

Task 3

"Prepare charts and other apparatus which may be used to demonstrate and explain the basic recommended method to the truck-trailer manufacturing industry and other interested groups."

A working model of a metering heat sink apparatus capable of measuring the heat leakage of a toy trailer was constructed for demonstration to the trailer industry. Figure 7 shows the circuit of this demonstration apparatus schematically which used ice for a cooling means and water as the secondary refrigerant or "brine". Figures 8 and 9 show two views of the demonstrator in operation. In Figure 9 the operator is measuring a temperature or temperature difference on the potentiometer. The calibrated heater can be seen under the inverted Dewar flask. Enlarged graphs showing the results of tests 1, 2, and 3 under Task 1 were prepared and used in conjunction with the working model of the metering heat sink.

Another working model of the metering heat sink, using a mechanical refrigerating unit, and a heated enclosure over the model trailer is shown in Figure 10. This model was constructed prior to the Tasks outlined in this report, but was modified for demonstration at several advisory group meetings of the Department of Agriculture.

Task 4

"After this has been done, the results of the research program up to that point will be presented to the truck-trailer manufacturing industry, at which time determination will be made jointly by the National Bureau of Standards, the U. S.

SCHEMATIC CIRCUITS FOR MODEL OF METERING HEAT SINK

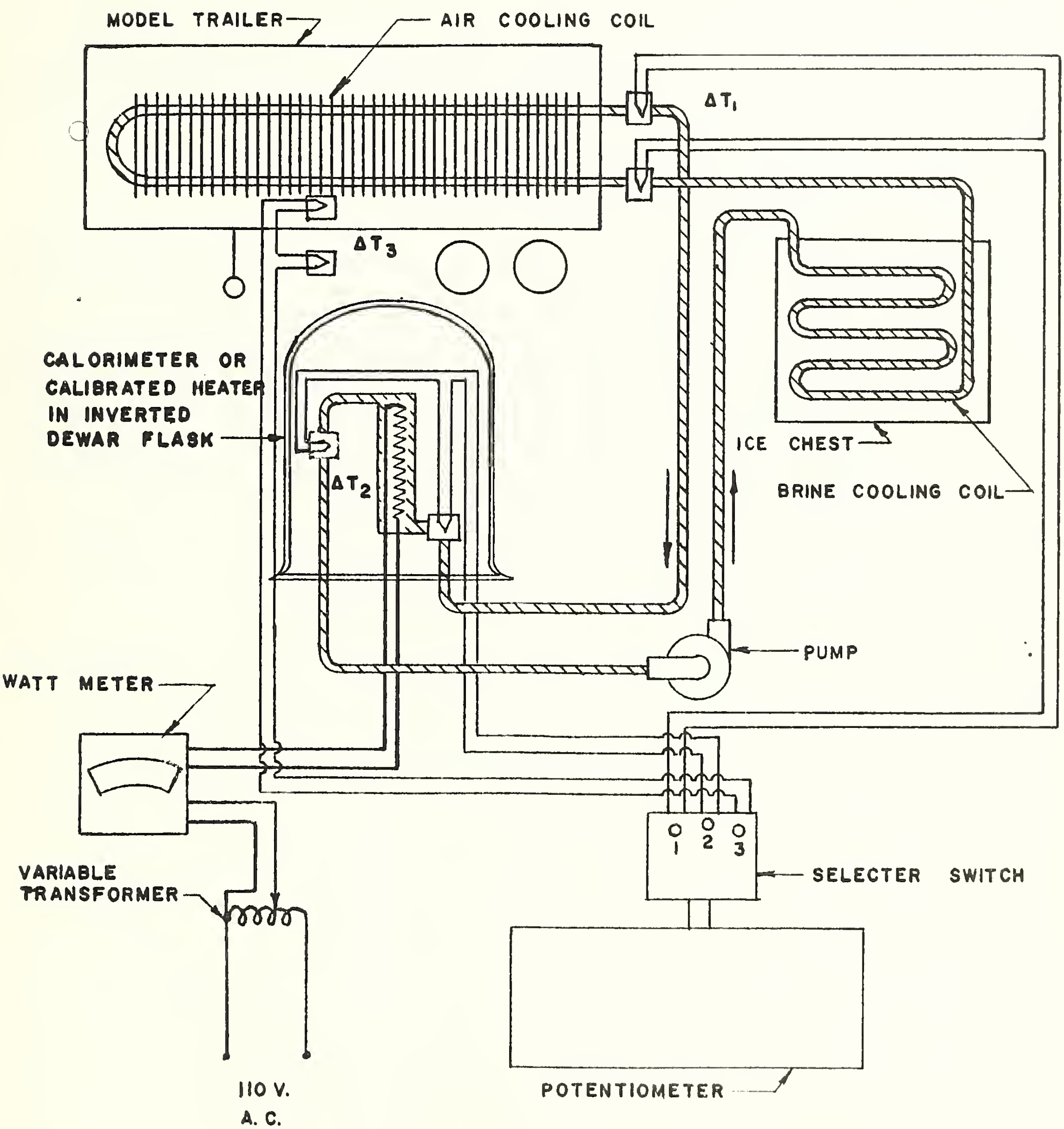


FIGURE 7

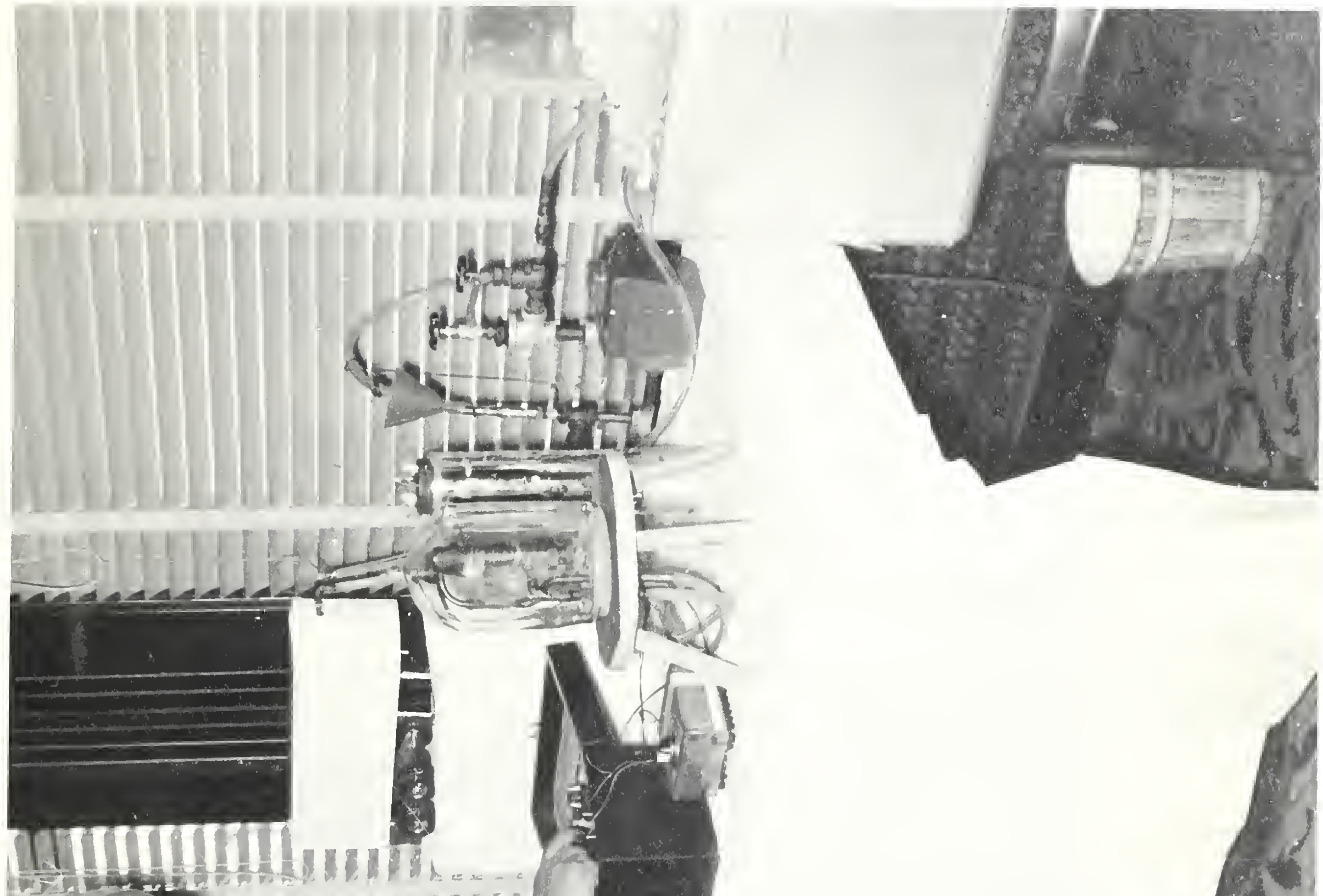


Figure 9

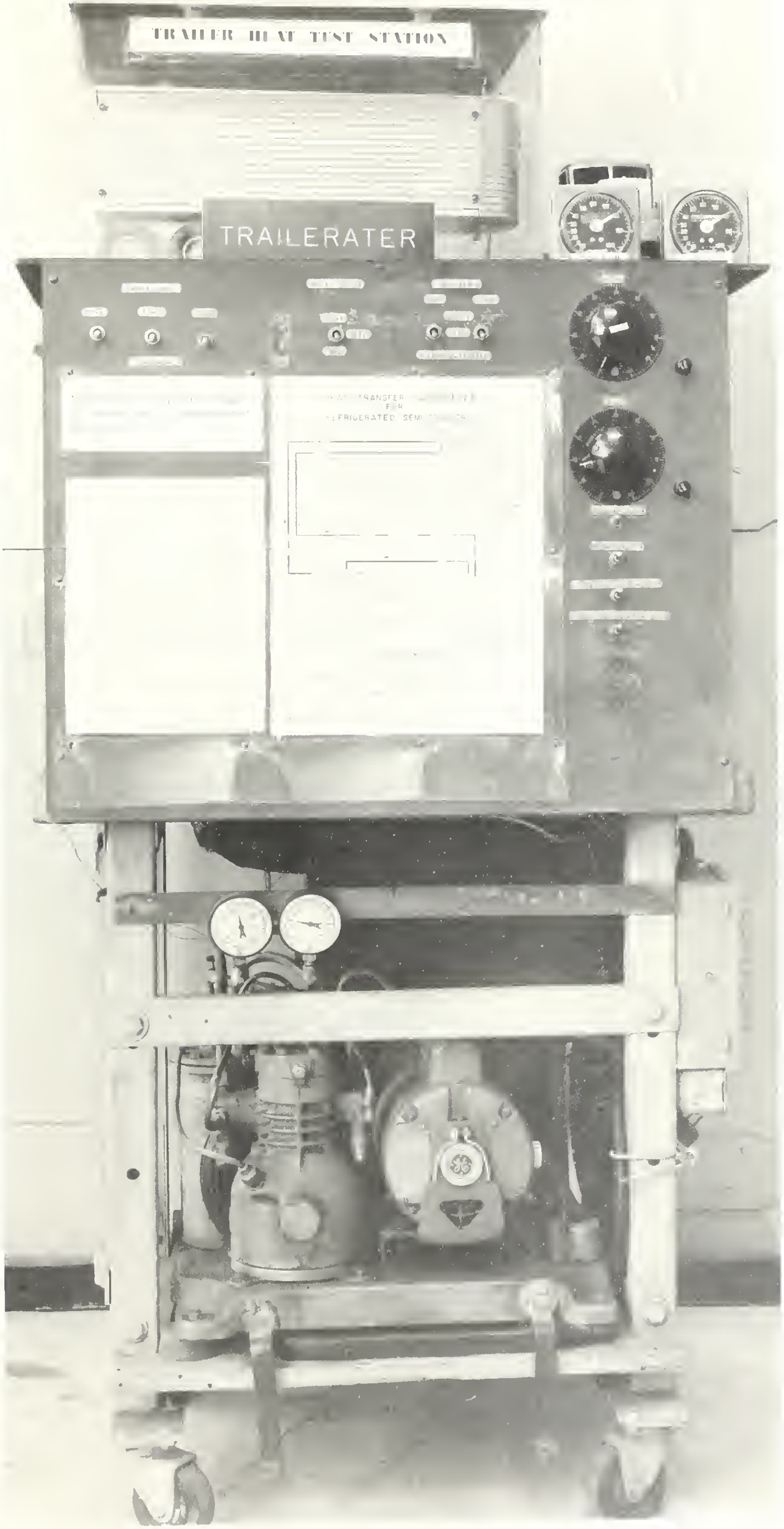


Figure 10

Department of Agriculture, and the Truck-Trailer Manufacturers Association as to further work to be done, to be supported primarily by funds contributed by that industry."

The working model of the metering heat sink shown in Figures 8 and 9 was demonstrated at a three day annual meeting of the Truck-Trailer Manufacturers Association in January, 1957, at the Coronado Hotel, Coronado, California. A discussion of the steps required to develop a standard method and conditions for rating refrigerated trailers was presented by representatives of the National Bureau of Standards and the Department of Agriculture at a meeting of the Refrigeration Committee of the Truck-Trailer Manufacturers Association during this same three day meeting. The results of the tests described under Task 1 were presented using charts and graphs and the working model of the metering heat sink described under Task 3.

Following this demonstration and discussion of the possibility of establishing such a standard rating method, the Board of Directors of the Truck-Trailer Manufacturers Association, at their final meeting at Coronado, voted to request the continued cooperation of both the U. S. Department of Agriculture and the National Bureau of Standards in this endeavor and further requested that these agencies prepare a proposal covering the necessary laboratory and field studies to develop a standard rating method for presentation at their next meeting which was scheduled for April, 1957, in Washington, D. C.

U. S. DEPARTMENT OF COMMERCE
Sinclair Weeks, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

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WASHINGTON, D. C.

Electricity and Electronics. Resistance and Reactance. Electron Tubes. Electrical Instruments. Magnetic Measurements. Dielectrics. Engineering Electronics. Electronic Instrumentation. Electrochemistry.

Optics and Metrology. Photometry and Colorimetry. Optical Instruments. Photographic Technology. Length. Engineering Metrology.

Heat and Power. Temperature Physics. Thermodynamics. Cryogenic Physics. Rheology and Lubrication. Engine Fuels.

Atomic and Radiation Physics. Spectroscopy. Radiometry. Mass Spectrometry. Solid State Physics. Electron Physics. Atomic Physics. Nuclear Physics. Radioactivity. X-rays. Betatron. Nucleonic Instrumentation. Radiological Equipment. AEC Radiation Instruments.

Chemistry. Organic Coatings. Surface Chemistry. Organic Chemistry. Analytical Chemistry. Inorganic Chemistry. Electrodeposition. Gas Chemistry. Physical Chemistry. Thermochemistry. Spectrochemistry. Pure Substances.

Mechanics. Sound. Mechanical Instruments. Fluid Mechanics. Engineering Mechanics. Mass and Scale. Capacity, Density, and Fluid Meters. Combustion Controls.

Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Organic Plastics. Dental Research.

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Building Technology. Structural Engineering. Fire Protection. Heating and Air Conditioning. Floor, Roof, and Wall Coverings. Codes and Specifications.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics.

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Radio Standards. Radio Frequencies. Microwave Frequencies. High Frequency Electrical Standards. Radio Broadcast Service. High Frequency Impedance Standards. Calibration Center. Microwave Physics. Microwave Circuit Standards.

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